Cosmic Strings in the Universe: Theory and Observations

Khovanskaya O.S., Sazhin M.V. [*], Capaccioli M.[†], Longo G.[‡]

E-mail to contact: khovansk@xray.sai.msu.ru

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The Capodimonte-Sternberg-Lens candidate No. 1 (CSL-1) is a peculiar double extended source discovered in the Osservatorio Astronomico di Capodimonte - Deep Field (OACDF).

CSL-1 consists of two giant elliptical galaxies at $z = 0.46 \pm 0.8\%$ with absolute magnitudes of $M_R = -22.3$ and with angular separation corresponding to 19 Kpc (Fig. 1).

The both components have identical morphologies, undistorted isophotes (Fig. 2) and identical spectra (Fig. 3) CSL-1 can be interpreted either as an very unlikely projection effect of two elliptical galaxies with identical magnitudes, morphology, colours and spectral properties or as the first case of gravitational lensing by a cosmic string. Detailed modeling shows that these two models can be easily disentangled by using high angular resolution imaging.

The detailed photometry and spectroscopy of CSL-1 allows us to indicate its main properties:

- The two images are well fit by de Vaucouleurs law and therefore are two ellipticals with absolute magnitude of $M_R = -22.3$ and angular separation corresponding to 19 Kpc;

- The absence of emission lines and the presence of the typical absorption features confirm that we are dealing with early type systems;

[*]Sternberg Astronomical Institute, Universitetsky pr., 13, 119992, Moscow, Russia

[†]INAF — Osservatorio Astronomico di Capodimonte, via Moiariello 16, I-80131 Napoli, Italy

[‡]Dipartimento di Scienze Fisiche, Univ. Federico II, Polo delle Scienze a della tecnologia, via Cinthia, 80126 Napoli, Italy

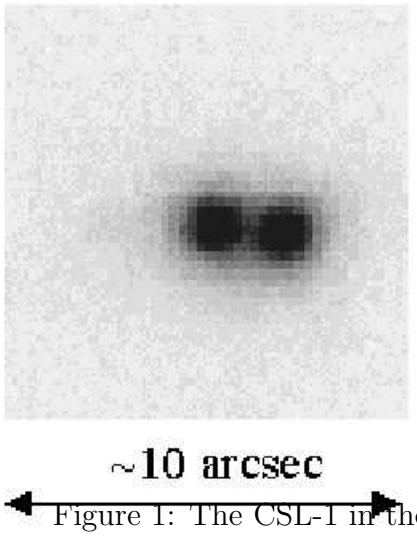

Figure 1: The CSL-1 in the R-band, 1 pixel = 0.238 arcsec

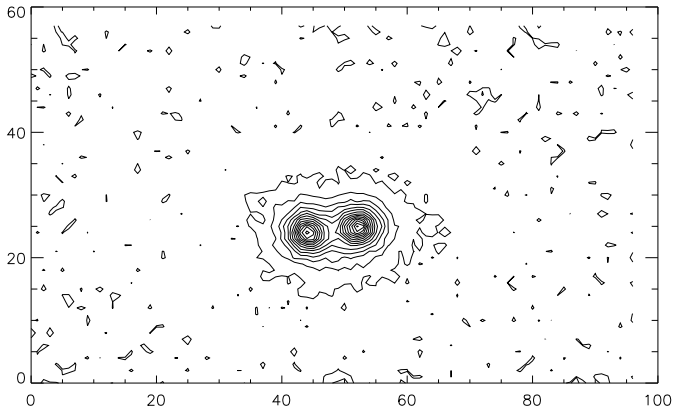

Figure 2: 2D contours of the CSL-1 from the near-infrared image λ914 nm

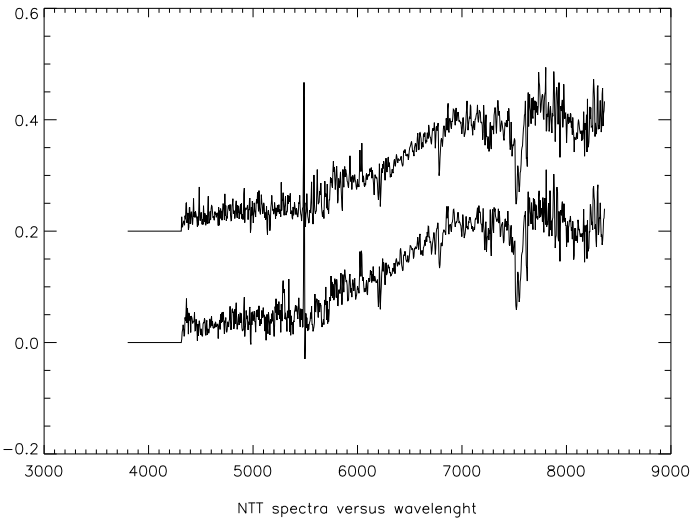

Figure 3: Spectra of two components of the CSL-1 on the European Southern Observatory New Technology Telescope (ESO NTT). A vertical shift was introduced for visualization purposes only.

- The spectra are identical with a confidence level higher than 99.999%, their difference is non gaussian noise.
- The undistorted isophotal shapes (obtained after careful adaptive smoothing of the data and removal of the bright central regions) allow us to conclude that the two system are not interacting.
- Even in our deepest images (24.5 in R band) we cannot see any trace of a lens between our two images this implying that if CSL-1 is the product of gravitational lens, such a lens should be a dark one.
- We can also rule out the possibility that the peculiar morphology of CSL-1 is produced by a very unlikely strong dust lane which should have a perfectly tailored shape and, in any case could not match simultaneously the observed profiles at the various wavelenghts.

Photometric and spectroscopic investigations suggest that it may be the first case of gravitational lensing by cosmic string.

There are a lot of problems in interpretation of CSL-1 as two identical galaxies. First of all, the spectra of the both components are identical with a confidence level higher than 99.999%. Second problem is that the physical distance between two galaxies must be limited. For the available in OACDF photometric accuracy 0.1, the minimal distance must be no less

than $L_{min} = 30$ Kpc because the observed isophotal shapes are undistorted and we do not observe the tidal interactions. The maximal distance between these galaxies must be no more than $L_{max} = 1000$ Mpc because we do not observe the gravitational lensing effect of one galaxy by other. For photometric accuracy 0.01 we have $[L_{min}, L_{max}]$ is approximately [60 Kpc, 50 Mpc]. The redshifts of two galaxies are identical ($\pm 0.8\%$) and the difference of peculiar velocities ΔV of two giant elliptical galaxies is ni more than 1000 km/sec. This way, the distance between two galaxies ΔL from the equation $\Delta V = H\Delta L$ is $\Delta L \leq 15$ Mpc (H is Hubble parameter in km/sec/Mpc).

The observed properties strongly support the interpretation of CSL-1 as a gravitationally lensed object because in all available in OACDF bands the isophots conserve the same almost circular shapes. However it is difficult to explain the nature of CSL-1 with standard lensing model. CSL-1 cannot be produced by lensing by a compact lens such as, for instance, a Singular Isothermal Sphere or any other model listed in the Keeton catalogue of models. Extended lensed objects would produce a significant distortion of the outer isophotes which is not observed in CSL-1.

One more consequence of such cosmic string scenario is that it predicts an excess of lensed objects in the region immediately surrounding CSL-1. More in details, in a 16×16 $arcmin^2$ region we expect to have ca. 10 gravitational lenses instead of the ≤ 2 predicted by the conventional gravitational lenses statistics. Such predictions seems to be supported by the fact that using very deep photometric multiband data and very strict morphological, photometric and colorimetric selection criteria we identified 11 lens candidates which now need to be confirmed by spectroscopic observations.

Therefore we are left with only two possible explanations: either we are dealing with a very unlikely projection effect of two identical galaxies laying along the line of sight (identical in terms of magnitudes, colors and, more relevant, also in terms of spectral properties, because the two spectra are identical at more than 99.999% confedence level); or we are seeing the effects of unconventional and so far never observed gravitational lens which does not distort extended images.

To exactly definition of the nature of CSL-1 we need the higher angular resolution image with large S/N ratio to observe the outer isophotes of CSL-1, where the sharp morphological signatures produced by a cosmic string are more evident (Fig. 4). We also need to prove by spectroscopic observations the gravitational nature of our 11 candidates in the CSL-1 field. Finally, in the case of two identical galaxies, we need the higher fotometric accuracy to

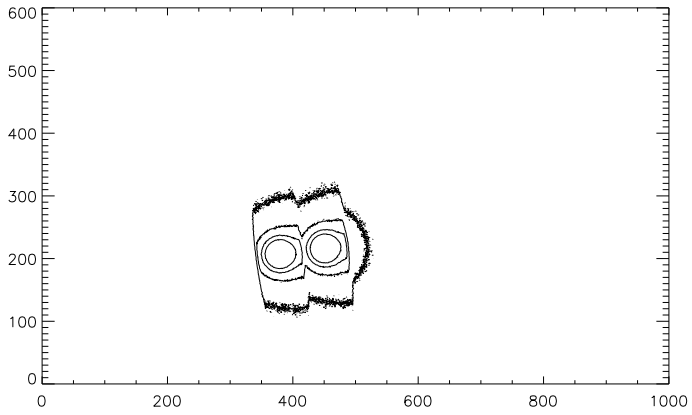

Figure 4: The simulations of the gravitational lensing effect of an elliptical galaxy on the cosmic string, the angular resolution 0.05 arcsec

decrease the available distance between these galaxies. If the distance will be less than L_{min} we will see the typical tidal distortions, if the distance will be more than L_{max} we will see the well known distortions where one galaxy is lensed by other galaxy. The higher photometric accuracy the less permissible distance between the galaxies will be.

Confirmation of the cosmic string hypothesis would allow us to derive an accurate measurements of the energy scale of symmetry breaking and of the energy scale of Grand Unification Theory, and will open a new way to investigate fundamental physics using astronomical instruments.